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Interactions of touch feedback with muscle vibration and galvanic vestibular stimulation in the control of trunk posture

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ABSTRACT

This study investigated the effect of touch on trunk sway in a seated position. Two touch conditions were included: touching an object with the index finger of the right hand (hand-touch) and maintaining contact with an object at the level of the spine of T10 on the mid back (back-touch). In both touch conditions, the exerted force stayed below 2 N. Furthermore, the interaction of touch with paraspinal muscle vibration and galvanic vestibular stimulation (GVS) was studied. Thirteen healthy subjects with no history of low-back pain participated in this study. Subjects sat on a stool and trunk sway was measured with a motion capture system tracking a cluster marker on the trunk. Subjects performed a total of 12 trials of 60-s duration in a randomized order, combining the experimental conditions of no-touch, hand-touch or back-touch with no sensory perturbation, paraspinal muscle vibration or GVS. The results showed that touch through hand or back decreased trunk sway and decreased the effects of muscle vibration and GVS. GVS led to a large increase in sway whereas the effect of muscle vibration was only observed as an increase of drift and not of sway. In the current experimental set-up, the stabilizing effect of touch was strong enough to mask any effects of perturbations of vestibular and paraspinal muscle spindle afference. In conclusion, tactile information, whenever available, seems to play a dominant role in seated postural sway and therefore has important implications for studying trunk control.

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1. Introduction

Control of trunk movement is crucial for maintaining balance during activities of daily living [1,2]. Also, precise hand/arm function is dependent on adequate control of trunk movement [3,4] and it has been suggested that impaired trunk control might induce instability of the lumbar spine and consequently cause low back pain [5,6] or play a role in low back pain recurrence [7,8]. Furthermore, control of trunk movement is affected in neurological disorders such as Parkinson's disease [9], stroke [10] and spinal cord injury [11].

Trunk control is dependent on adequate motor control as the intrinsic stiffness of the trunk is insufficient [12]. In turn, proper motor control depends on adequate sensory feedback. The influence of different sensory modalities in feedback control is often studied by interfering with these modalities and measuring the resulting changes in motion [13–15]. Furthermore, the involuntary/reflexive component of trunk control can be identified by applying external perturbations and measuring the resulting trunk muscle responses [16,17]. These external perturbations require application of time-varying forces to the subject's trunk. This usually involves contact with an external object for the whole or a part of the test duration. However, there is evidence that contact with an external object may, through tactile information, have a profound influence on postural control [18–20].

The effect of tactile stimuli on postural control has been illuminated specifically in studies of standing postural sway. For example, when subjects stand upright and their calf muscles are vibrated, to interfere with muscle spindle information, a large increase in sway is observed [21]. However, when subjects are allowed to keep a very light contact through the hand with an external object, this effect of muscle vibration is strongly reduced. Still, several questions remain unanswered. First, is the effect of touch specific for contact with the hand, or does it apply to other body areas as well? Second, does the effect of touch interact specifically with muscle vibration, or does it interact also with other sensory modalities? Furthermore, for the purpose of understanding trunk control, measurements of standing postural sway provide limited information, since postural adjustments can be made in several joints (e.g. ankle, knee, hip). Therefore, the measured sway can be attributed to several joints and might not accurately reflect trunk control. In sitting, trunk control can be

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studied without the influence of responses from the lower extremities.

The purpose of the current experiment was to determine the effect of touch on trunk sway in a seated position. To investigate whether the effect is specific for touch with the hand, a second contact condition, namely contact through the back, was included. Finally, to determine whether the effect of touch interacts specifically with muscle vibration, or also with other sensory modalities, a second sensory perturbation, galvanic vestibular stimulation (GVS), was included. It was hypothesized that touch through both hand and back reduces the effects of muscle vibration and GVS. The results obtained may contribute to a better understanding of the influence of touch on the control of trunk posture.

2. Methods

2.1. Experimental setup

The study was approved by the ethical committee of the faculty of human movement sciences of the VU University Amsterdam. 13 Healthy subjects without history of low-back pain participated (10 males, 3 females; age range: 20–35 years; mean mass: 77 (SD 10) kg; mean height: 182 (SD 8) cm). Subjects sat upright on a height adjustable stool with their feet on the ground at shoulder width apart and their knees bent at a 90° angle (Fig. 1). Trunk sway was measured with a motion capture system (Optotrak 3020, Northern Digital Inc., Canada) tracking, at 100 Hz, a cluster of 3 markers attached to the back at the level of the spine T6.

Subjects performed a total of 12 trials of 60-s duration in a randomized order, combining the experimental conditions of no-touch, hand-touch or back-touch, with no sensory perturbation, muscle vibration or GVS. Since the eyes were closed for the muscle vibration and GVS to have a stronger effect, an eyes open condition was included to check whether closing the eyes affects trunk sway. During selected trials, subjects were allowed to touch a solid object attached to a force sensor. During all touch conditions, the force exerted on the force sensor was monitored by the experimenter and never exceeded 2 N to assure that the mechanical stabilizing advantage was kept to a minimum. Hand-touch was provided between shoulder and elbow height in the mid-sagittal plane and back-touch was provided at the level of the spine of T10 in the mid-sagittal plane. During all trials, the subject's arm was held in the same (hand-touch) position to prevent any effects of changing arm posture. During the trials with muscle vibration, a custom made vibrator was attached bilaterally to the lower back at the level of L4, 5 cm lateral of the spine. The vibrator was turned on right

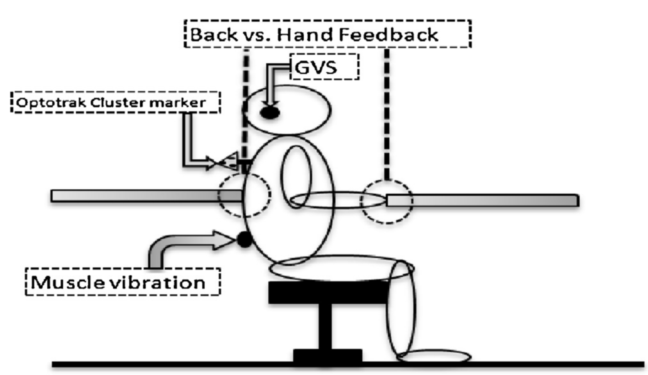

Fig. 1. A schematic drawing of the experimental set-up. Trunk sway was measured with a cluster marker attached on the back at the level of the spine T6. Muscle vibration was applied bilaterally on the lower back at the level of the spine L4. Hand-touch was provided at elbow height in front of the body while back-touch was provided in the mid-sagittal plane at the level of the spine T10.

before the onset of the trial and the vibration frequency was set to 90 Hz.

For the GVS trials, a direct current was applied to the mastoid processes by a custom-made constant current stimulator (Balance Lab, Maastricht Instruments, The Netherlands). The current was applied as a sinusoid with a frequency of 1 Hz and 1.5 mA amplitude [22]. Subjects were instructed to rotate their head sideways ('look over your shoulder') to induce illusory movement in the fore-aft direction. Furthermore, to eliminate possible effects of turning the head, subjects were instructed to maintain their head turned sideways during all trials.

2.2. Data analysis

Per trial, the first and last 10 s of the signal were discarded to eliminate transient behavior, leaving 40 s which were used for further data analysis. The average position of the cluster marker in the sagittal plane was calculated. Preliminary analysis showed that a considerable drift occurred, especially during the vibration trials. Accordingly, the analysis was split into two parts. First, the signals were corrected for drift by applying a linear piecewise detrend and, subsequently, trunk sway in the fore-aft direction (sagittal plane) was quantified by calculating the standard deviation of the detrended signals. Second, to analyze the effects of touch condition on drift, the drift of the raw data was quantified by calculating the difference between the average position during the first and last second of the 40-s signal. Quantifying the drift by a 3- or 5-s window led to similar results.

2.3. Statistical analysis

To investigate whether closing the eyes affected trunk postural sway, a repeated measures ANOVA with 2 factors (touch condition, eyes open vs. closed) was performed. To determine whether trunk sway was affected by touch and/or perturbation conditions, a 2 factor (touch condition, perturbation condition) repeated measures ANOVA was performed. Furthermore, a similar ANOVA was performed on the calculated drift. Significant main effects were followed up by Bonferroni corrected pair-wise comparisons. Effects were considered significant when the corrected $p < 0.05$. The assumption of normality was checked by visual inspection of the q–q plots and box plots of the residuals. A Shapiro–Wilk test was also performed on the residuals. There was no violation of the assumption of normality. Sphericity was checked using Mauchly's test. If the assumption of sphericity was violated, a Greenhouse–Geisser correction was used [23].

3. Results

A typical example of the measured position of the trunk in fore-aft direction for a reference (eyes closed) and muscle vibration trial is presented in Fig. 2.

The ANOVA results are presented in Table 1. Closing the eyes did not significantly affect trunk sway ($p = 0.6$) (Fig. 3, top panel). Trunk postural sway was significantly reduced in the hand-touch ($p = 0.01$, 95% CI [−0.371 −0.050]) as well as in the back-touch condition ($p = 0.016$, 95% CI [−0.425 −0.042]) (Fig. 3, top panel). For the perturbation conditions, only GVS led to a significant increase in sway ($p = 0.015$, 95% CI [0.036 0.337]). A trend for an increase in trunk sway could be observed for the muscle vibration condition (Fig. 3, top panel), but failed to reach statistical significance (95% CI [−0.062 0.193]). There was no significant interaction of perturbation and touch condition.

Significantly more drift was observed for the muscle vibration condition compared to the reference ($p < 0.001$, 95% CI [3.920 13.413]) and GVS conditions ($p < 0.001$, 95% CI [4.973 13.359])

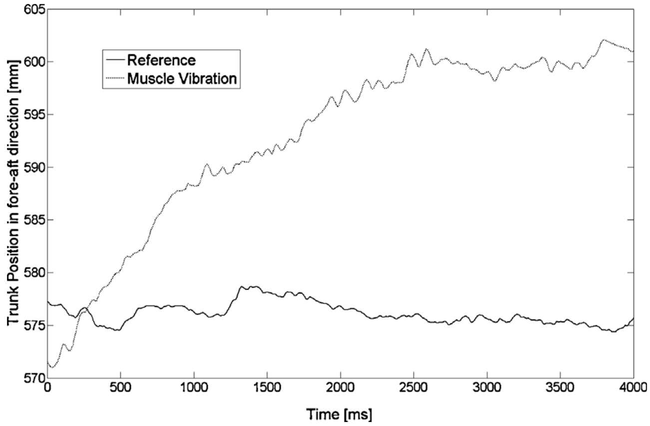

Fig. 2. A typical example of the position of the trunk in fore-aft direction for a reference (eyes closed) trial and a trial with muscle vibration, showing considerable drift.

(Fig. 3, lower panel). Furthermore, a significant interaction was present, indicating that for the vibration condition, hand-touch was effective in decreasing the drift compared to the no-touch condition ($p = 0.019$, 95% CI [−3.978 −0.348]). Back-touch also decreased the drift in the vibration condition but this failed to reach statistical significance on post hoc tests (Fig. 3, lower panel).

4. Discussion

The purpose of the present experiment was to determine the effect of touching an external object on trunk postural sway in a seated position. Furthermore, the possible interaction of touch with paraspinal muscle vibration and GVS was studied. The results showed that touch through hand or back was effective in decreasing trunk sway and in decreasing the effects of muscle vibration and GVS. GVS led to a large increase in sway whereas closing the eyes did not significantly affect sway. The effect of muscle vibration was only observed as an increase of drift and not of sway.

The results demonstrated an important factor in studying trunk control: the possible interference of touch with other sensory modalities. In the current experimental set-up, the stabilizing effect of touch was strong enough to mask any effects of manipulation in the vestibular and paraspinal muscle spindle afference. These results are consistent with findings from standing postural sway: for example, Lackner et al. showed that in standing postural sway, allowing the subjects to touch a laterally positioned surface strongly decreased the observed (lateral) sway, even in the presence of vibration to the m. peroneus longus and brevis tendons [21].

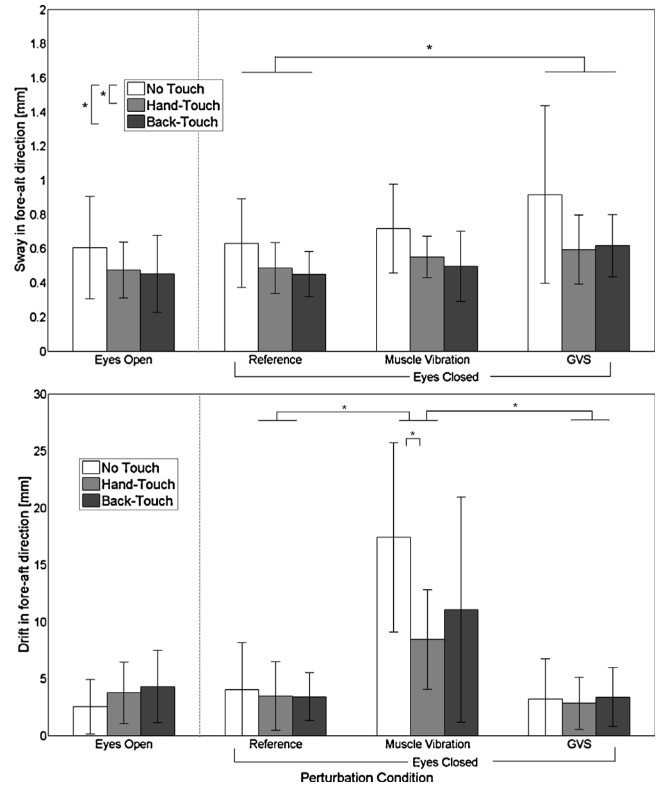

Fig. 3. Mean sway (top panel) and drift (lower panel) in fore-aft direction. Error bars represent one standard deviation. * denotes significance at the $p < 0.05$ level. In the top panel, a significant main effect for both touch and perturbation condition was found. In the lower panel, a significant main effect for perturbation was found. Furthermore, a significant interaction was present indicating the significant difference between vibration hand-touch and vibration no-touch.

Several studies have shown that vestibular information plays an important role in postural control [13,24]. The present results support these findings as perturbing the vestibular organ with GVS resulted in a large increase in sway. Muscle vibration led to a strong increase in drift and a trend for an increase in sway could also be observed. These results are consistent with other experiments [25,26].

Several mechanisms for the stabilizing effect of touch have been proposed. In standing postural sway, the exerted touch force was well below the force that one might expect to result from the movement due to sway. Therefore, touching an external object can be expected to have a non-significant mechanical stabilizing effect in this case. In a seated position, the observed sway is considerably smaller; hence, the mechanical stabilizing effect of a light (<2 N) touch may be relatively large compared to standing. However, Jeka

Table 1
Main and interaction effects of both ANOVAs for sway and for drift.

	F	df	*p*	Pairwise comparisons
Sway				
Touch condition[a]	10.724	1.4–16.7	0.002	No touch > hand touch
				No touch > back touch
Perturbation condition	5.631	2–24	0.010	GVS > reference
Touch × perturbation	0.684	4–48	0.606	–
Drift				
Touch condition	3.116	2–24	0.063	–
Perturbation condition[a]	32.082	1.5–17.6	< 0.001	Vibration > reference
				Vibration > GVS
Touch × perturbation[a]	3.313	3.0–36.5	0.030	Vibration/no touch > vibration hand touch

[a] Denotes Greenhouse–Geisser correction due to a violation of the assumption of sphericity.

and Lackner showed that, in standing, allowing the subjects to assert higher touch-forces did not lead to an additional stabilizing effect [19]. Therefore, it is likely that sensory mechanisms largely determined the stabilizing effect of touch.

A second possible contribution to the stabilizing effect of touch might be of proprioceptive nature. When the subject touches an external object, for example with the hand, a change in trunk posture will lead to changes in all joints connecting the trunk to the external object (shoulder, elbow, wrist). This may provide the subject with additional information about trunk sway. However, the results from Rabin et al. do not support the contribution of proprioceptive information from the arm to be the only stabilizing factor [29]. In the study of Rabin et al., subjects were instructed to stand in a heel-to-toe stance, making them more unstable in the lateral direction. Furthermore, the heel-to-toe standing subjects were allowed to touch in front of the body (stable sway direction) or to the side (unstable sway direction). The results showed that when subjects were allowed to touch in the unstable sway direction (e.g. to the side for heel-to-toe stance), the reduction in sway was larger compared to touch in the stable direction [27]. Since the amount of rotation in the arm joints was independent of touch direction, it is unlikely that proprioceptive information from the arm joints was the only contributor to the stabilizing effect.

Finally, the results from Rabin et al. suggest that tactile feedback may contribute to the stabilizing effect. The pressure receptors in contact with the external object provide the subject with additional information of his/her sway. Two factors may influence the contribution of the sensory information. First, the amount of available pressure receptors might affect the amount of available information. In this case, one would expect a larger effect of hand-touch as the hand has a larger density of pressure receptors compared to the back [30]. Secondly, if the contact point is used as a passive pressure probe, one would expect a larger effect of back-touch as the contact point on the back is more directly coupled to the trunk and therefore better suited as a "pressure gauge" for deviations of the trunk. However, the current findings indicate that hand- and back-touch are equally effective in reducing sway suggesting that both aforementioned factors contribute similarly.

The present findings have important implications for studying trunk control. Many methods for studying trunk control apply external perturbations, which implies that the body is in contact with an external object. The present findings indicate that irrespective of the body part in contact with the external object, the tactile information has a strong influence on postural control. For example, the contribution of other sensory modalities to postural control becomes difficult to investigate because the dominant effect of touch will mask any effects of perturbations to these sensory modalities. Even when the touch-surface is not stable but when moving rhythmically, as is often the case with external perturbations, the influence of touch is dominant as the body sway is strongly coupled to the moving touch-surface [28–30]. For future research, it would be interesting to combine a moving touch-surface with interference of other sensory modalities, for example GVS and/or muscle vibration, to see whether the interference can still be observed in the postural sway.

The current study has several limitations. First, since the available information was limited, an a priori power analysis was not performed. Therefore, a post hoc Monte Carlo power analysis was performed to check whether the obtained power was sufficient. This power analysis indicated that sufficient power was obtained for all effects except for the sway interaction effect. Given the limited power, the absence of an interaction should be interpreted with care and our results suggest that effects of other sensory inputs may be difficult to detect when tactile information is available.

A second limitation was the age of the sample population, which consisted of healthy young adults. The present results might not be representative of older adults and/or patients as it has been shown that proprioceptive reweighting might change with age [30] and low-back pain [26].

In conclusion, tactile information, whenever available, seems to play a dominant role in the control of trunk posture in young healthy adults.

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Conflict of interest

The authors declare that no conflicts of interest were associated with the present study.

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